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SPAWNING BIOMASS OF THE NORTHERN ANCHOVY IN 1990

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By

Larry D. Jacobson and Nancy C. H. Lo

ADMINISTRATIVE REPORT LJ-90-20

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SPAWNING BIOMASS OF THE NORTHERN ANCHOVY IN 1990

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SUMMARY

Management of the central subpopulation of northern anchovy (Engraulis mordax) by the Pacific Fishery Management Council includes a harvest quota which varies annually as a function of the estimated spawning biomass in each year (Pacific Fishery Management Council 1983).

The spawning biomass of northern anchovy (Engraulis mordax) in the central subpopulation on 15 February 199C was estimated to be 466,000 mt. The total biomass of northern anchovy in the central subpopulation on 15 February 1990 was estimated to be 517,000 mt. The estimates were obtained using the Stock Synthesis Model for anchovy (Methot 1989; Jacobson and Lo 1989) modified to include a new index of relative abundance based on aerial survey data (Lo, in prep.) and a new "shrinkage" estimator for recruitment during recent years (see below).

In the course of producing an estimate of the spawning biomass during 1990, the estimates of spawning and total biomass for 1989 (used by the Council last year to set quotas for 1989) were substantially revised. Current estimates of the spawning and total biomass during 1989 are 158,000 mt and 307,000, respectively. Last

year's estimates of the spawning and total biomass during 1989 were 237,000 mt and 1,008,000 mt, respectively. The differences are due, primarily, to age composition and relative abundance data not available during 1989.

MODEL

The Stock Synthesis Model (Methot 1986; Methot and Lo 1987; Lo and Methot 1989; Jacobson and Lo 1989 and Methot 1989) has been used on an annual basis since 1986 to estimate the spawning biomass of northern anchovy. The Stock Synthesis Model is an age-structured model parameterized such that predicted values for indices of relative abundance and predicted values for age composition of catches agree with available data. Parameters in the model are estimated by maximizing a composite likelihood function (Methot 1986, 1989).

The model used for the 1990 spawning biomass estimate was identical to that used for the 1989 estimate except for the following modifications. Firstly, the oldest age group included in the model for the period 1987-1990 was increased from 4+ to 5+ to accommodate the appearance since 1987 of fish aged 5 and older in catches by the Mexican reduction fishery. Anchovy age 5 and older

became rare in U.S. and Mexican landings after 1979 (Mais 1981) but have constituted up to 7% of the total number of fish landed by the Mexican reduction fishery since 1987.

Another modification consisted of eliminating four parameters from availability calculations in the model because variances for the parameter estimates were large (i.e. coefficients of variation were between 80% and 260%) and because precision of biomass estimates improved when the parameters were eliminated. There were several other parameters with large variances that were not eliminated either because they were required in the model or because the precision of biomass estimates deteriorated when they were eliminated.

The final modification to the model was intended to deal with a problem with the 1989 spawning biomass estimate for anchovy noted by Jacobson and Lo (1989, p. 11-12 and Figure 3). They noted that biomass estimates for the most recent year appear to be inaccurate or imprecise due, they suggest, to uncertainty about the abundance of new recruits (one-year-old anchovy). The problem seems to diminish with time so that estimates for the years prior to the most recent year are progressively less affected. In order to deal with this difficulty, a Bayesian "shrinkage estimator" (Whittemore 1989) was employed for recruitment of one-year-olds in 1989 and 1990.

The shrinkage estimator is a weighted average of the maximum likelihood estimate for recruitment in a particular year and the mean recruitment observed for previous years:

$$R_y = w\ M + (1-w)\ L_y, \qquad [1]$$

where R_y is the shrinkage estimate for recruitment of one-year-old anchovy in year y, w is a weighting factor between zero and one, M is the mean recruitment during previous years, and L_y is the likelihood estimate for recruitment in year y. The weighting factor (w) reflects the relative reliability of mean recruitment (M) and values from the Stock Synthesis Model (L_y) as estimators for recruitment of one-year-old anchovy. The estimator [1] "shrinks" the final estimate (R_y) towards the mean (M) if the likelihood estimate (L_y) is unreliable. For example, if the likelihood estimate was thought to be imprecise relative to natural variability in recruitment levels, then a weighting factor (w) close to one would be appropriate.

A value for the weighting factor (w) can be chosen minimize the squared error loss (sum of squared differences between true and estimated values of R_y) if information about the variability in true recruitment levels and precision of likelihood estimates is available. This information was not available, however, so a weighting factor of 0.9 was used to estimate recruitment of one-year-old anchovy in 1990 and a value of 0.45 was used to estimate recruitment of one-year-old anchovy in 1989. Mean recruitment was

calculated from the likelihood estimates for 1964-1987 which were little affected by the problem as described above.

GENERAL DATA REQUIREMENTS

Data used for the 1990 biomass estimate as well as in previous years (e.g. Jacobson and Lo 1989) include: 1) spawning biomass (EPM) as estimated by the Egg Production Method (Lasker 1985), 2) an index of historical egg production (HEP) which is related to spawning biomass (Lo 1985), 3) an index (MHEP) of historical egg production modified to account for changes in survey design (Methot and Lo 1987), 4) biomass of schooled fish as measured by the California Department of Fish and Game (CDFG) using sonar (Mais 1974), 5) age composition data from commercial and survey catches, 6) weight at age data from commercial and survey catches, 7) total landings data, 8) mean monthly sea surface temperatures at Scripps Pier 9) estimated annual abundance of Pacific Mackerel (Scomber japonicus), 10) the fraction of age 1 females determined to be actively spawning by visual examination during CDFG surveys during late winter, and 11) the fraction of age 1 females determined to be sexually mature by histological examination. Weight at age and age composition data from Mexican and US commercial fisheries as well as US survey fisheries are used. Not all of the data described above are available for all years (Table 1).

A new index of schooling biomass (Lo, in prep.) was used in the Stock Synthesis Model for the 1990 spawning biomass estimate. The new index (denoted AERIAL) is based on aerial survey data collected by pilots employed by commercial fishing interests to locate and identify schools of fish. AERIAL is the product of three terms:

$$AERIAL_y = D_y P_y A_y, \qquad [2]$$

where $AERIAL_y$ is the index for year y, D_y is an estimate of the density (short tons/positive flight blocks) of anchovy for flights during which anchovy were observed, P_y is an estimate of the proportion of blocks searched during positive flights (positive flight blocks/total blocks), and A_y is an estimate of the geographic extent (total blocks) of the anchovy population. The product of the first two terms (D_y and P_y) gives the density of anchovy in all blocks. The third term (A_y) accounts for changes in the area covered by the population. Estimates of anchovy density (D_y) and proportion positive blocks (P_y) were obtained using general linear models (similar to linear regression models) that account for differences among pilots, seasons, time of day and other factors. The area covered by the population (A_y) is estimated from the area actually covered by the aerial survey.

NEW DATA

Environmental Data

The mean sea surface temperature at Scripps Pier during and preceding the spawning season in 1990 was near normal (Table 1). The mean temperature for January-February 1990 (the peak of spawning for northern anchovy) was 14.4° C compared to 13.0° C for January-February 1989 and the long term (since 1960) January-February mean temperature of 14.2° C. Temperatures during and preceding the spawning season are important with respect to estimates of anchovy spawning biomass because sexual maturity of one-year-old fish depends on water temperatures (Methot 1989). At 14.4° C, about 85% of one-year-old fish are sexually mature and contribute to the spawning biomass. Note that the January-February temperature for 1989 reported here (13.0° C) differs from the value (12.5° C) reported by Jacobson and Lo (1989) due to correction of an error in Scripps Pier daily sea surface temperature data.

Mean sea surface temperatures at Scripps pier during the 1989 fishing season were lower than normal during January and February, higher than normal during April and near normal during other months. Temperatures during the fishing season are thought to affect the distribution of fish, their availability to the fisheries and the size at age observed in the Mexican fishery (Methot and Lo 1987).

Egg Production Data

Production of eggs by anchovy during March of 1990, as indicated by the MHEP index, was 1.85 eggs/0.05 m2/day (standard error = 0.68) which can be compared to the estimate of 1.54 eggs/.05 m^2/day (standard error = 0.55) for January, 1989 (Table 1, Figure 1). Spawning biomass and egg production during 1989 were reduced due to low temperatures during the spawning period (Jacobson and Lo 1989). The slightly higher MHEP value for 1990 suggests that egg production and the spawning biomass have increased. It should be noted, however, that MHEP estimates are not precise (coefficients of variation since 1985 have ranged from 35%-43%, Table 1). Furthermore, the MHEP estimate for 1989 was for January which is early in the season while the MHEP estimate for 1990 was for March which was late in the season. Imprecision in the MHEP index and differences among years in sampling dates make interpretation of small interannual changes in the MHEP difficult. Note that the MHEP for 1989 reported here (1.54 eggs/0.05 m^2/day) differs from the value (2.39 eggs/0.05 m^2/day) reported by Jacobson and Lo (1989) due to correction of an error in calculation.

Aerial Survey Data

The aerial survey index for February 1990 was 27,421 mt (standard error = 16,820) which can be compared to 12,254 mt (standard error = 5,476) for 1989 (Table 1, Figure 2). These data suggest a modest increase in biomass of schooling biomass between

1989 and 1990. As with the MHEP data, however, imprecision in the index makes interpretation of small interannual changes in the MHEP difficult. This problem is exacerbated in connection with the value for 1990 because it was estimated from aerial survey data for January-February whereas figures for earlier years were based on twelve months of data.

Fishery Data

Monthly landings (Table 2) data for the Mexican reduction fishery during 1989 were provided by the Centro Regional Investigacion de Pesquera (W. Garcia, pers. comm.). Monthly landings data from the US fishery during 1989 (Table 2) were provided by CDFG (T. Dickerson, pers. comm.).

The Mexican reduction fishery harvested 80,823 mt of northern anchovy during 1989 while the US live bait, reduction and non-reduction fisheries harvested 7,044 mt of northern anchovy (Table 1). The total catch during 1989 was 87,867 mt which can be compared to 84,886 mt in 1988 and 129,350 mt in 1987 (Table 1).

Weight at age (Table 3) and age composition data (Table 4) for the Zapata fleet operating out of Ensenada, Baja California were provided by Living Marine Resources (Tom Barnes, pers. comm.).

Mean weights at age for anchovy ages 1-3 landed by the Mexican fishery during the second and third quarters of 1989 were 2.6 g and 7.3 g heavier than average (Figure 3). Anchovy landed in Mexico during 1988 were also large; anchovy ages 1-3 were 2.7 g, 3.7 g and 2.6 g larger than average in the second, third and fourth quarters,

respectively (Jacobson and Lo 1989). These results are surprising since water temperatures during the last three quarters of 1988 and second and third quarters of 1989 were warmer than normal. Cold water is thought to increase size at age of anchovy landed by the Mexican fishery because large and older fish remain in the south in order to avoid the relatively cold northern waters (Methot and Lo 1987 and Lo; Methot 1989).

Anchovy in the 1989 year class (age zero in 1989) recruited to the Mexican fishery earlier and constituted a greater proportion of the total catch than usual (Figure 4). The age composition data for 1989 show unusually high proportions of age zero fish in the second, third and fourth calendar quarters. Patterns in recruitment of age zero fish to the Mexican fishery in 1989 are similar to those observed for age zero fish in 1988 (Jacobson and Lo 1989).

The early appearance of age zero fish during 1988 and 1989 and their greater than average size suggests a number of hypotheses. Age zero anchovy that appeared early than normal in 1988 and 1989 may have resulted from spawning peaks that occurred earlier than normal. It is possible that the 1988 and 1989 year classes were unusually abundant and/or grew at a rate that was faster than normal. This explanation seems unlikely for the 1988 year class, at least, because current estimates for the abundance of the 1988 year class do not suggest that the year class was a large one (see below). It is also possible that undescribed environmental factors affected the growth of anchovy and/or age and date of recruitment.

Another explanation for the early appearance of new recruits and large sizes of anchovy during recent years is that increased size is due to low anchovy biomass resulting in reduced intraspecific competition for food and that early appearance of new recruits in the fishery is due to a scarcity of older fish. This explanation is consistent with data from the Ensenada fleet that were not included in this analysis. It should be noted, however, that the Ensenada fleet operates on the southern edge of the distribution of northern anchovy which makes data difficult to interpret, old anchovy (ages 5 and older) have become increasingly common in the Mexican fishery since 1987 (see above) which suggests increased survival rates, and that fishery independent indices of abundance (i.e. MHEP and AERIAL, Table 1) used for the 1990 biomass estimate do not indicate that biomass levels were low.

In the Stock Synthesis Model, recruitment occurs, by definition, at age 0.5 years at the beginning of the third 'pseudo-quarter' (pseudo-quarters are approximately the same as calendar quarters, see Jacobson and Lo 1989) and age zero fish encountered prior to the beginning of the third pseudo-quarter are assumed to be age one fish that were mis-aged. The age composition data for most years are compatible with this definition because relatively few age zero anchovy are typically observed prior to the second calendar quarter (Lo and Methot 1989). It seems unlikely, however, that the age zero fish observed during May-June 1988 and May-June 1989 were actually age one because they constituted more than 33% of the total catch during those months. For the 1989 spawning

biomass estimate, the discrepancy between age composition data for 1988, age composition data for previous years and the structure of the model was diminished by grouping the data for 1988 into pseudo-quarters as described by Jacobson and Lo (1989). For the 1990 estimated spawning biomass, however, age composition, landings and mean weight at age data for 1989 were grouped by calendar quarter and data for age zero fish taken during quarters one and two were omitted. This ad-hoc approach will suffice for the present but we intend to modify the model to eliminate the problem prior to estimation of the spawning biomass for 1991.

Monthly catch, age composition and weight at age data for each year are grouped into pseudo-quarters for use with the Stock Synthesis Model (Methot 1986). Months in each year are assigned to pseudo-quarters in such a way as to make the catch, age composition and weight at age data for each pseudo-quarter as consistent as possible. Months included in each pseudo-quarter may differ from one year to the next as well as between the US and Mexican fisheries in any particular year. For the 1989 calendar year the data for January-March were grouped to form the first pseudo-quarter. Data for April were used for the second pseudo-quarter and all age zero fish observed in April were assumed to have been age one fish that were mis-aged. Data for May-July were grouped to form the third pseudo-quarter and data for August-December were grouped to form the fourth pseudo-quarter (Tables 3-5). This approach to grouping the data effectively delays the appearance of new recruits until the beginning of the third pseudo-quarter and

tends to reduce the estimated abundance of new recruits (age zero fish) during 1988.

Pacific Mackerel

Natural mortality of northern anchovy in the Stock Synthesis Model varies from year to year on the basis of Pacific Mackerel biomass levels. A biomass estimate for Pacific Mackerel on 1 July 1990 consistent with previous estimates (Jacobson and Lo 1989) was not available due to problems with data and changes in analytical procedures. Preliminary catch-at-age analyses indicated, however, that mackerel biomass may be high in 1990. In lieu of a figure for 1990, Pacific mackerel biomass was set equal to the value for 1986 and 1987 (500,000 mt) which is the highest value in the time series of Pacific mackerel biomass levels. The effect of using a high value for Pacific mackerel biomass during 1989 is to reduce the estimates anchovy biomass for 1990. Results obtained using the Stock Synthesis Model are, however, typically not sensitive to the level of Pacific mackerel mortality (Methot 1986) which suggests that the data used in this analysis probably suffice as an indicator of Pacific mackerel biomass.

RESULTS

The estimated spawning biomass for the central subpopulation of northern anchovy on 15 February 1990 was 446,000 mt which can be compared to 158,000 mt in 1989 and 287,000 mt in 1988 (Table 5, Figure 5). The estimated total biomass for northern anchovy on 15 February 1990 was 517,000 mt which can be compared to 307,000 mt in 1989 and 298,000 mt in 1988 (Table 5, Figure 5).

FUTURE RESEARCH

Alec MacCall (pers. comm.) has pointed out that the shrinkage estimator based on mean recruitment levels (described above) would tend to result in biomass estimates that are too high during years when recruitment and spawning biomass are lower than normal. High biomass estimates, in turn, could lead to harvest quotas that are too high. He suggested that a shrinkage estimator based on mean recruits per spawner, rather than mean recruitment, would lead to fewer problems in this regard. We intend to pursue this suggestion prior to estimation of the spawning biomass for 1991.

It has also been suggested that ages assigned to small fish in catches taken prior to July during 1988 and 1989 should be checked by counting daily rings in otoliths. This would allow unambiguous assessment of the age of putative new recruits taken during the first half of the calendar year.

ACKNOWLEDGEMENTS

We thank W. Garcia (Centro Regional Investigacion de Pesquera) for providing landings and age composition data through the MEXUS-PACIFICO program, T. Barnes (Living Marine Resources, Inc.) for providing age composition data, T. Dickerson (California Department of Fish and Game) for providing data from U.S. fisheries and P. Wolf (California Department of Fish and Game) for providing Pacific Mackerel biomass estimates.

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Table 1. Abundance survey, temperature, Pacific mackerel biomass and landings data used in the Stock Synthesis Model for northern anchovy. TEMP is mean January-February sea surface temperatures (deg C.), MACK is pacific mackerel biomass (million mt) on 1 July, US is landings by US fisheries, MEX is landings by the Mexican fishery, TOTAL is total landings and all other abbreviations are defined in the text.

YEAR	EPM	HEP	SONAR	MHEP	AERIAL	TEMP	MACK	US	MEX	TOTAL
64		4.15		8.64	8.5	15.0	0.05	6966	4599	11565
65		4.02		8.18	6.9	13.3	0.02	8246	9171	17417
66		5.26		12.85	13.0	13.8	0.01	34394	13243	47637
67					17.3	14.0	0.01	36473	20104	56577
68					4.6	14.5	0.01	20740	14267	35007
69		3.82	438	5.43	16.3	14.3	0.01	66253	3871	70124
70			275		14.9	13.6	0.01	92853	27977	120830
71			233		16.6	13.1	0.01	46484	20079	66563
72		1.66	822	3.45	16.4	12.8	0.01	67994	30047	98041
73			1671		62.9	15.0	0.01	125966	15424	141390
74			947		51.1	13.1	0.01	80166	44987	125153
75		19.69	3086	16.71	82.7	13.2	0.01	149377	56877	206254
76					47.5	13.9	0.01	119529	75746	195275
77			1984		44.6	16.0	0.10	107541	142575	250116
78		2.33	392	14.66	45.6	15.7	0.13	17470	140001	157471
79		5.43	292	5.07	79.6	13.9	0.29	58608	204585	263193
80	870	2.67	604	2.55	54.6	15.0	0.25	56234	245797	302031
81	635	4.38	567	4.74	28.5	14.6	0.33	56234	258700	314934
82	415	3.29	250	1.68	23.7	14.1	0.36	51837	177587	229424
83	652	3.91	532	1.65	5.5	15.9	0.24	8487	79389	87876
84	309	2.85	573	2.57	13.6	15.0	0.16	7302	101118	108420
85	521	2.62	1015	5.16	45.8	13.8	0.46	5784	121081	126865
86				7.56	15.5	15.2	0.50	5504	96417	101921
87				7.23	14.4	15.0	0.50	4875	124475	129350
88				6.89	39.9	14.0	0.29	5656	79230	84886
89				1.54	12.3	13.0	0.12	7044	80823	87867
90				1.85	27.4	14.4	0.50			

Table 2. Landings (mt) for northern anchovy taken by the Mexican (MEX) and US fisheries during 1989.

MONTH	MEX	US	TOTAL
JAN	0	68	68
FEB	20	132	152
MAR	60	227	287
APR	4730	421	5151
MAY	6989	621	7610
JUN	13378	972	14350
JUL	18826	1068	19894
AUG	9342	1145	10487
SEP	15761	810	16571
OCT	11718	579	12297
NOV	0	518	518
DEC	0	483	483
TOTAL	80823	7044	87867

Table 3. Monthly mean weight at age data (grams wet weight) from the Mexican reduction fishery during 1989.[1] Figures in square brackets are sample sizes.

Month	Age Group 0	I	II	III	IV	V+
April	11.8 [12]	14.6 [191]	16.8 [211]	19.2 [90]	19.7 [36]	20.3 [15]
May	8.9 [128]	15.8 [70]	18.8 [107]	21.3 [54]	22.4 [14]	21.5 [8]
June	10.0 [196]	15.8 [88]	19.5 [54]	21.8 [27]	22.0 [9]	27.4 [5]
July	10.7 [260]	19.8 [20]	24.6 [23]	26.7 [9]	28.3 [4]	33.1 [4]
August	11.1 [316]	18.2 [27]	22.6 [11]	26.5 [2]	23.8 [2]	30.4 [2]
September	9.6 [325]	16.3 [28]	22.0 [3]	24.2 [3]	24.1 [1]	23.2 [1]

[1] Data for the Zapata fleet provided by Living Marine Resources, Inc. (T. Barnes, pers. comm.)

Table 4. Monthly age composition data (% by number of each age group in samples) from the Mexican reduction fishery during 1989.[1] Figures in parentheses are sample sizes.

Month	Age Group 0	I	II	III	IV	V+
April (N=554)	2.2	34.4	38.1	16.2	6.5	2.7
May (N=380)	33.6	18.4	28.2	14.1	3.7	2.0
June (N=379)	51.8	23.2	14.2	7.1	2.5	1.2
July (N=320)	81.3	6.1	7.3	2.7	1.4	1.1
August (N=359)	88.0	7.5	3.0	0.5	0.5	0.5
September (N=359)	90.4	7.7	0.7	0.7	0.3	0.1
October (N=251)	71.3	17.9	7.6	2.8	0.4	0.0

[1]Data for the Zapata fleet provided by Living Marine Resources, Inc. (T. Barnes, pers. comm.)

Table 5. Estimated spawning stock biomass (SPAWN) and total biomass (TOTAL) for northern anchovy during 1964-1990 (thousand mt).

YEAR	TOTAL	SPAWN
64	488	482
65	529	399
66	441	410
67	306	293
68	345	323
69	355	334
70	334	266
71	515	231
72	876	429
73	1527	1492
74	1842	1261
75	1576	1355
76	1093	1065
77	908	907
78	493	493
79	852	574
80	773	766
81	780	744
82	404	375
83	544	525
84	401	394
85	666	538
86	690	682
87	615	608
88	298	287
89	307	158
90	517	466

Figure 1. Modified egg production (MHEP) data (eggs/.05 m^2/day) for anchovy with nominal 95% confidence intervals.

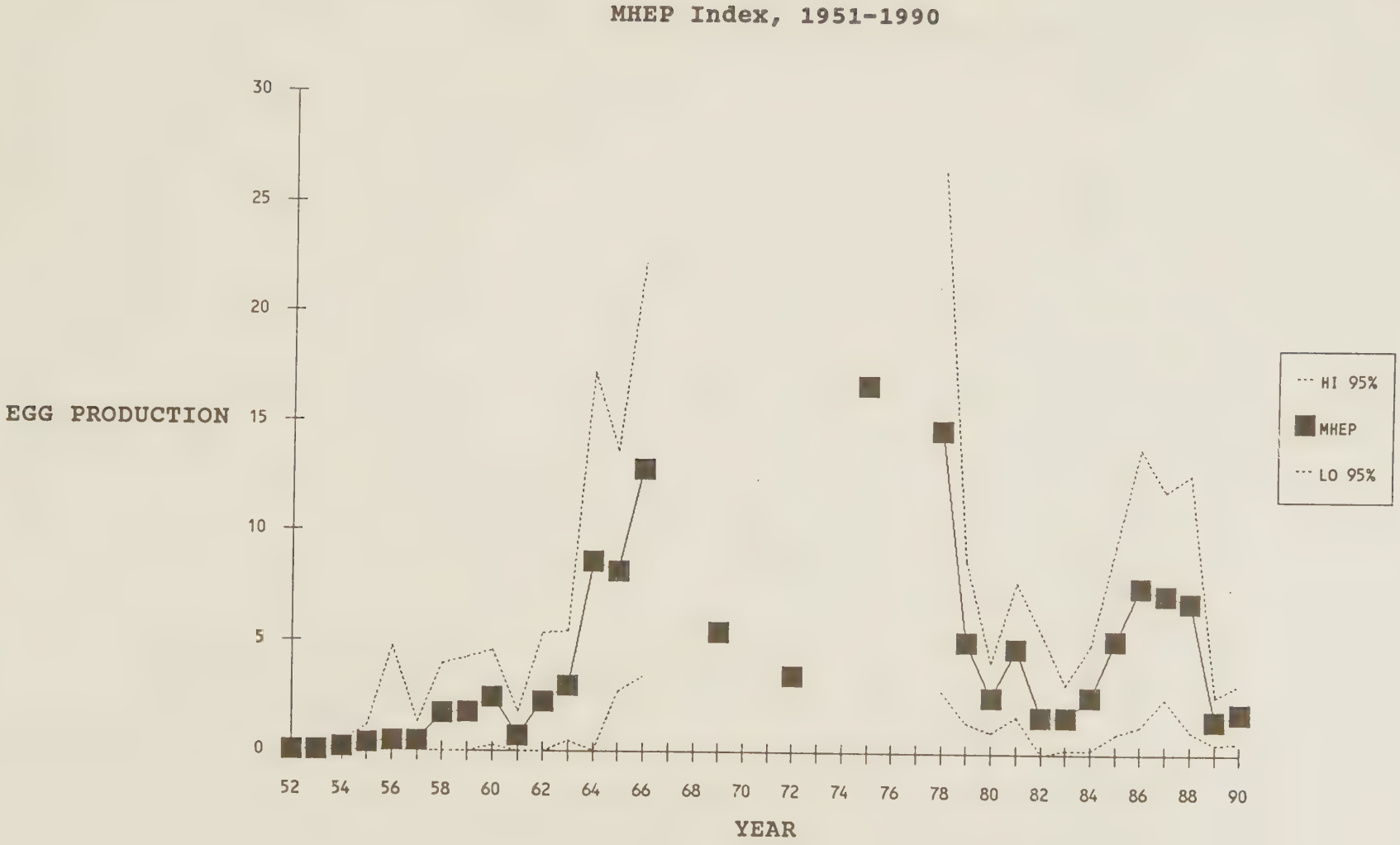
MHEP Index, 1951-1990
EGG PRODUCTION
YEAR
30
25
20
15
10
5
0
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90
HI 95%
MHEP
LO 95%

Figure 2. Aerial survey index (short tons) for anchovy schooling biomass during February of 1964-1990 with nominal 95% confidence intervals.

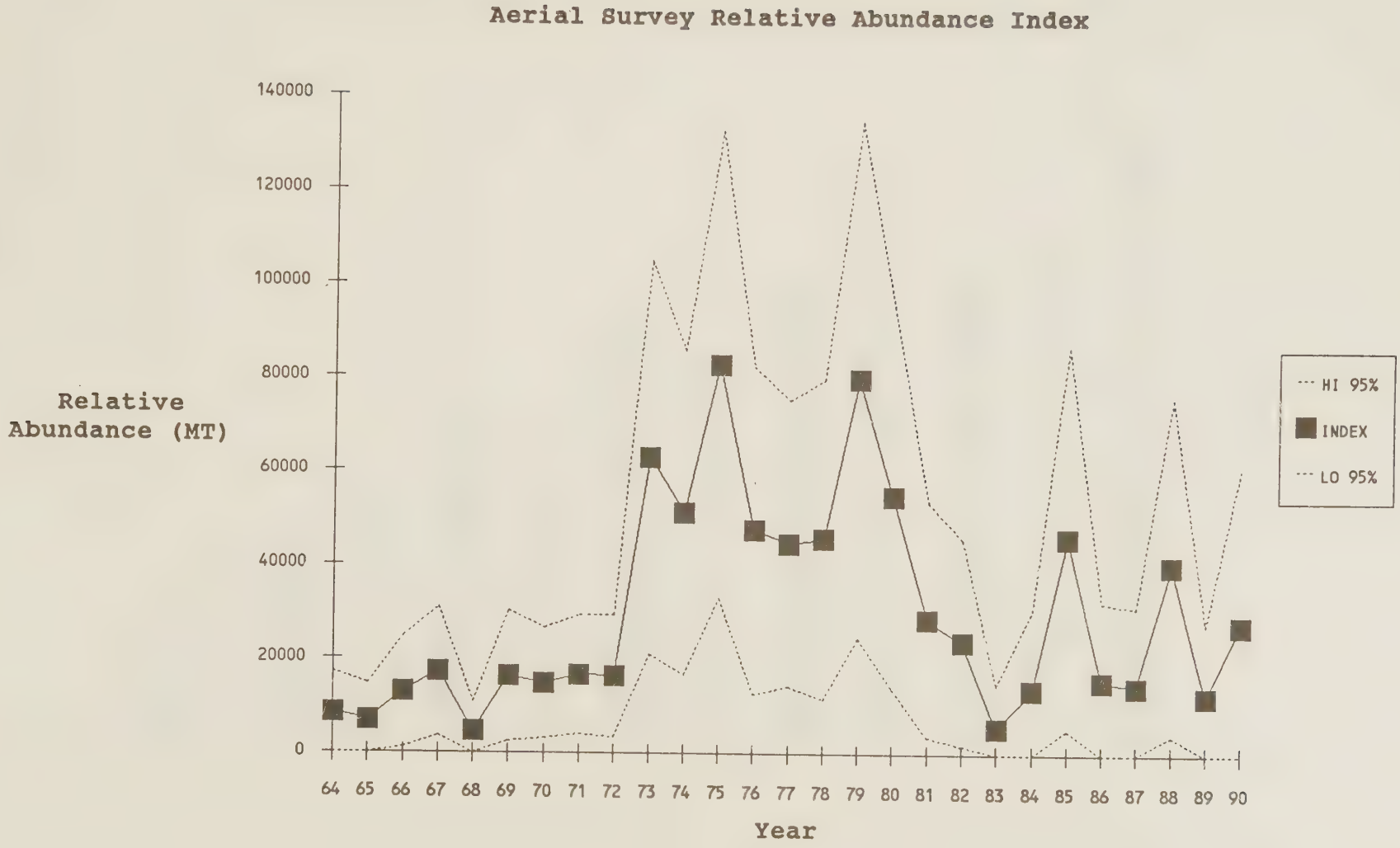
Aerial Survey Relative Abundance Index
Relative Abundance (MT)
140000
120000
100000
80000
60000
40000
20000
0
64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90
Year
HI 95%
INDEX
LO 95%

Figure 3. June mean weight at age data for anchovy taken by the Mexican fishery. Data for 1988, 1989 and mean values for 1964-1988 are shown.

JUNE WEIGHT AT AGE DATA FOR ANCHOVY IN MEXICAN FISHERY

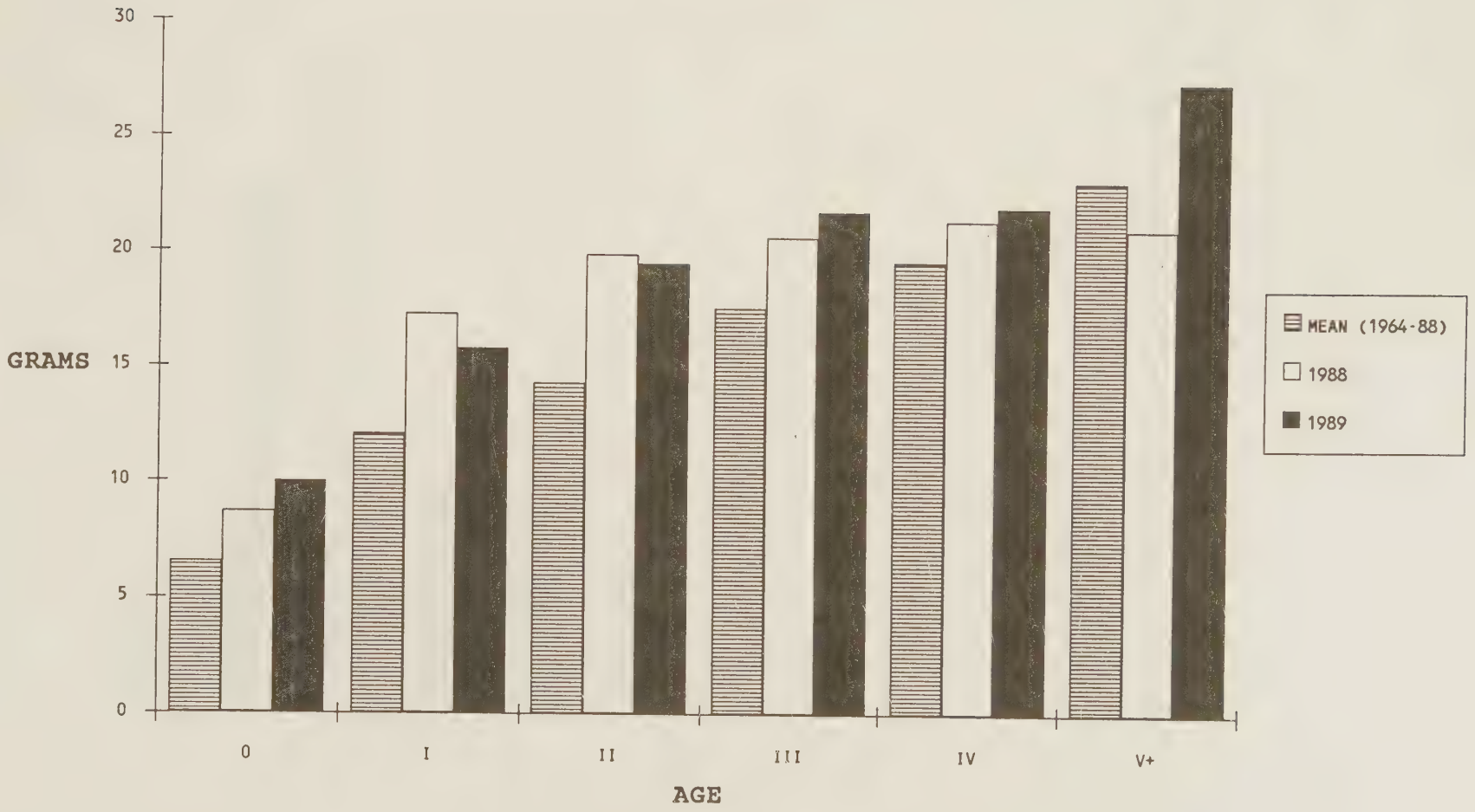

Figure 4. June age composition data for anchovy taken by the Mexican fishery. Data for 1988, 1989 and mean values for 1964-1988 are shown.

JUNE AGE COMPOSITION DATA FOR ANCHOVY IN MEXICAN FISHERY

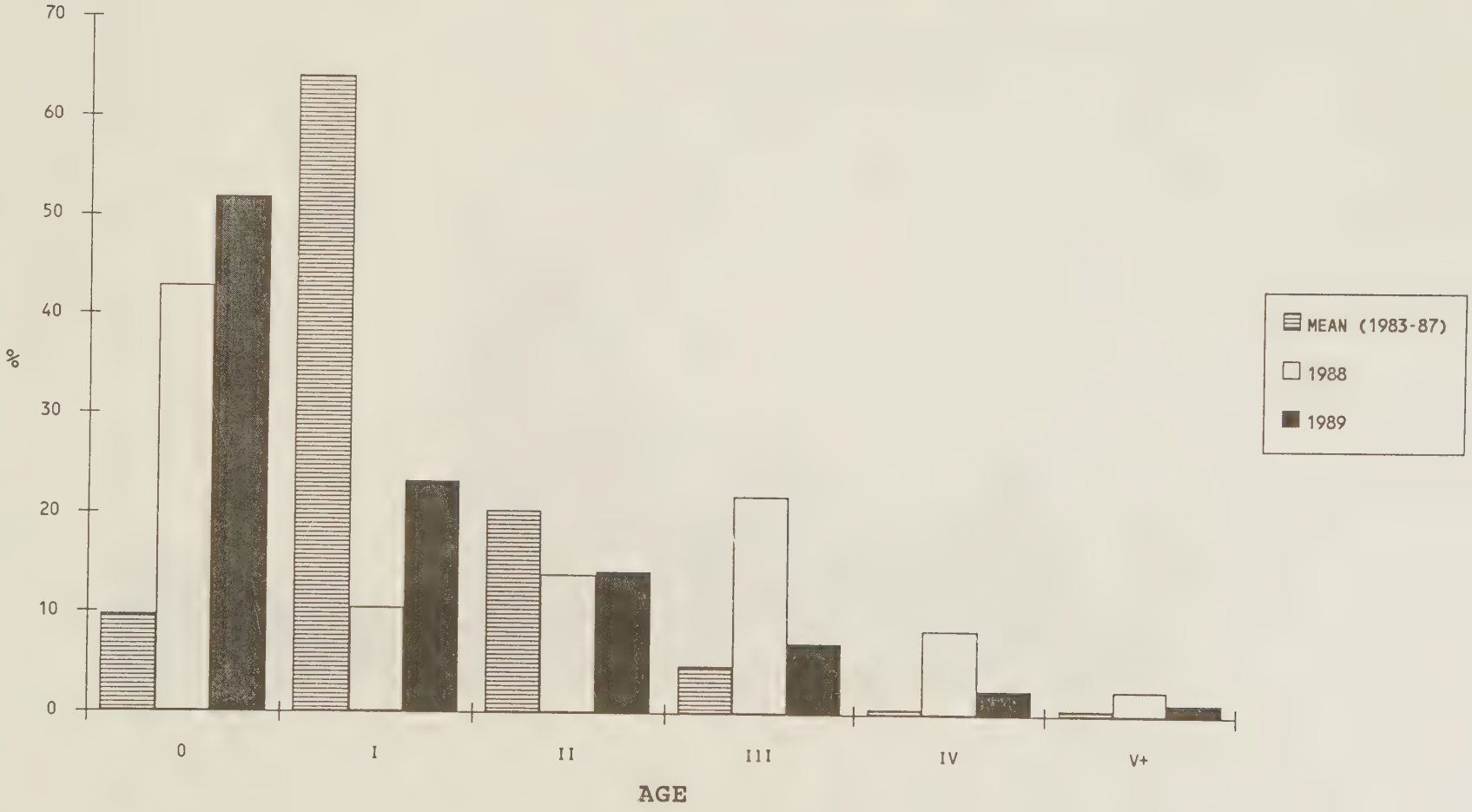

Figure 5. Estimated spawning stock biomass and total biomass during 1964-1990. Biomass values are given in units of 10^3 mt.

ESTIMATED ANCHOVY BIOMASS, 1964-1990